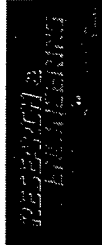


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1. REPORT DATE		2. REPORT TYPE Viewgraphs		3. DATES COVERED	
4. TITLE AND SUBTITLE  Fiber Sensors for Aircraft Health Monitoring				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  Ignacio Perez				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Naval Air Warfare Center Aircraft Division 22347 Cedar Point Road, Unit #6 Patuxent River, Maryland 20670-1161				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  Naval Air Systems Command 47123 Buse Road Unit IPT Patuxent River, Maryland 20670-1547				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ignacio Perez
Unclassified	Unclassified	Unclassified	Unclassified	23	19b. TELEPHONE NUMBER (include area code) (301) 342-8074



# FIBER SENSORS FOR AIRCRAFT HEALTH MONITORING

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Naval Air Warfare Center  
Aircraft Division, Patuxent River MD 20678

SAE Avionics Systems Division  
Sept 19 - 22, 1999  
Sheraton Four Points Hotel  
San Diego CA 92123

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# OUTLINE

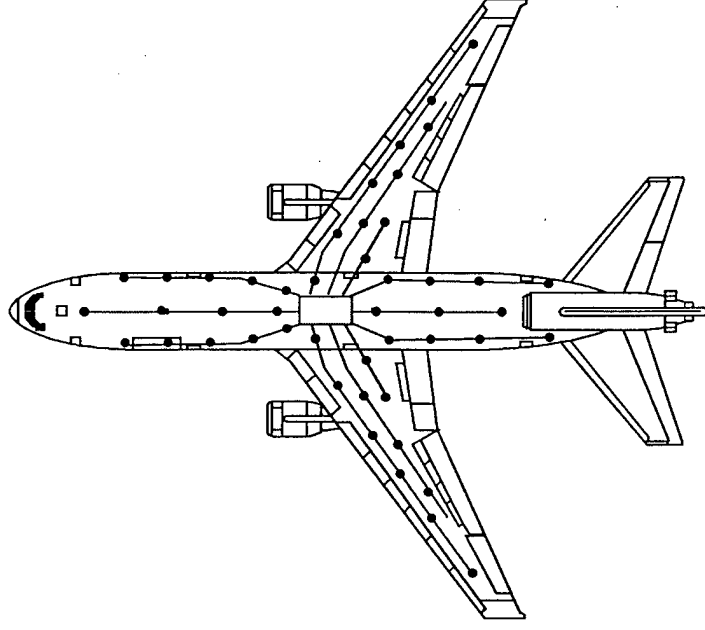
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- Objective
- Why Health Monitoring
- Sensor Requirements
- Fabrication Methods
- Bragg Grating Sensors
  - Strain and temperature monitoring
  - AE Monitoring
  - Bondline monitoring
  - Corrosion Monitoring
- Discussion - Recommendation

# OBJECTIVE

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- To study, develop and transition fiber sensor technologies for aircraft health monitoring. To develop reliable readout electronics and analysis software



# Why Health Monitoring ?

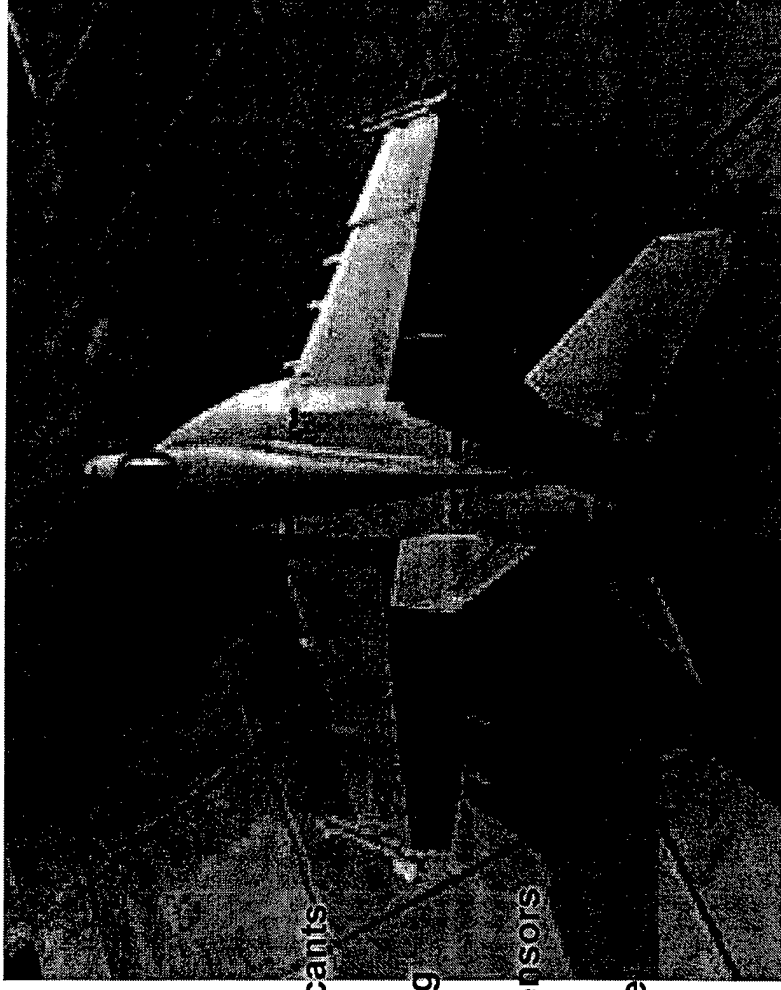
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The main purpose of aircraft health monitoring is for reducing maintenance cost and enhancing aircraft useful life

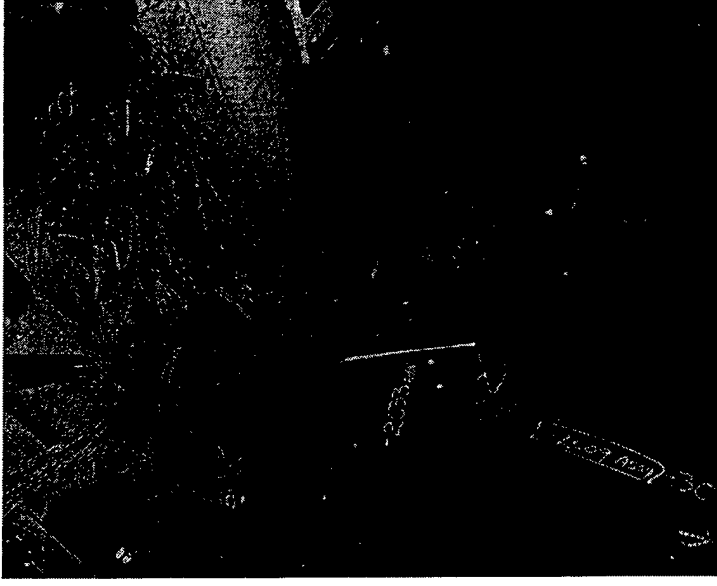
- Health Monitoring of Rotating Engine Parts
- Distributed Bond line Monitoring system
- Distributed Crack Initiation and Growth Monitoring System
- Distributed Corrosion Monitoring System

## What parameters could be monitored in an aircraft ?

- Engine Monitoring
  - Cracks in disks, blades
  - Flow parameters
  - Temperature
- Gear box
  - Wear and cracks in gears
  - Vibration
- Viscosity and particulate in lubricants
- Structural Monitoring
  - Full scale fatigue tests monitoring
  - Aircraft validation
  - Acoustic emission monitoring sensors
  - Vibration Monitoring
  - Strain monitoring sensors (usage)
  - Impact damage monitoring
  - Bond integrity monitoring
  - Temperature monitoring
  - Humidity monitoring
  - Buffet monitoring



# Full Scale Fatigue Test



Wiring for strain sensor instrumentation during a full scale fatigue test. Every sensor requires a minimum of two electrical leads. Each sensor requires a calibration file. Special care has to be taken to avoid EMI.

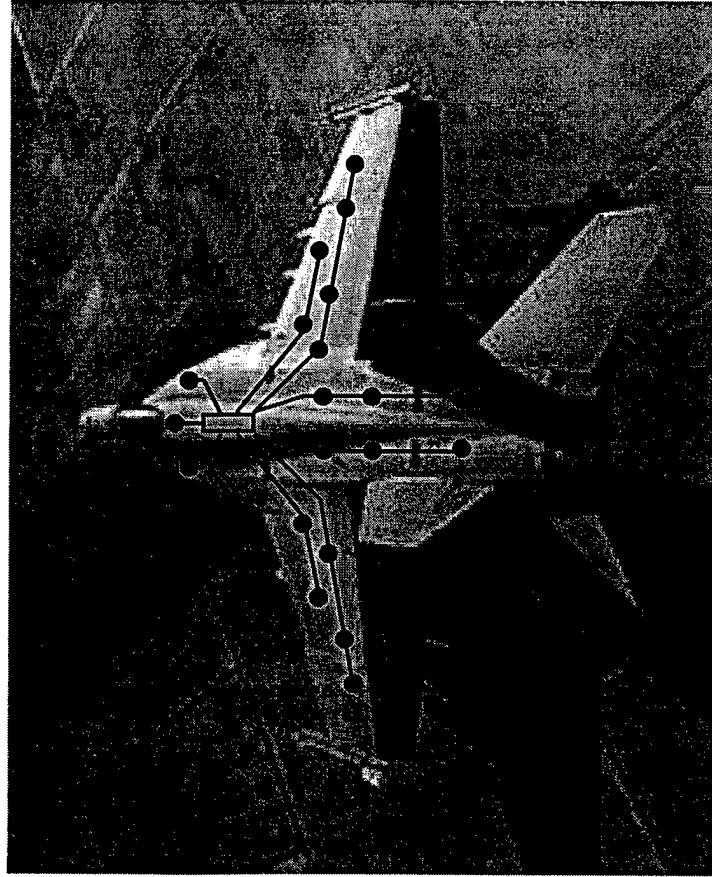
# SENSOR REQUIREMENTS

## Sensors have to be:

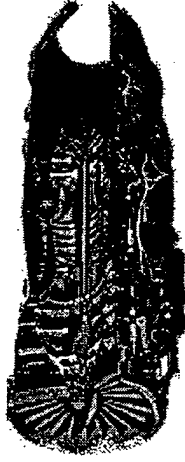
- Small volume
- Light weight
- Easy to connect
- Easy to multiplex
- Temperature resistant
- Rugged
- Reliable
- Easy to interrogate
- Accurate
- Minimum power requirements
- Minimum EM shielding requirements
- Corrosion resistant
- Easy to repair



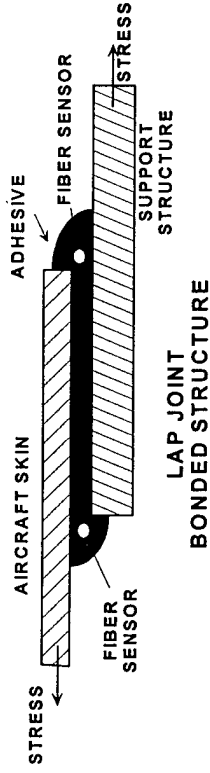
## Health Monitoring System



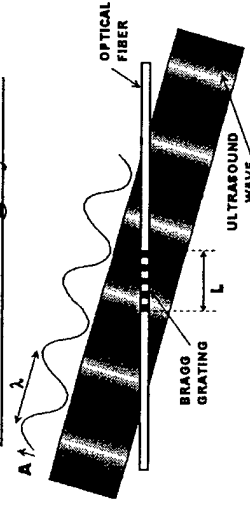
### Engine Monitoring System



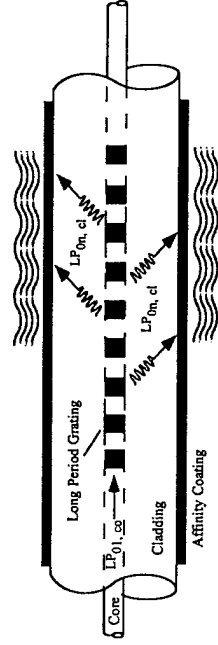
### Bondline Monitoring System



### AE Monitoring System



### Corrosion Monitoring System

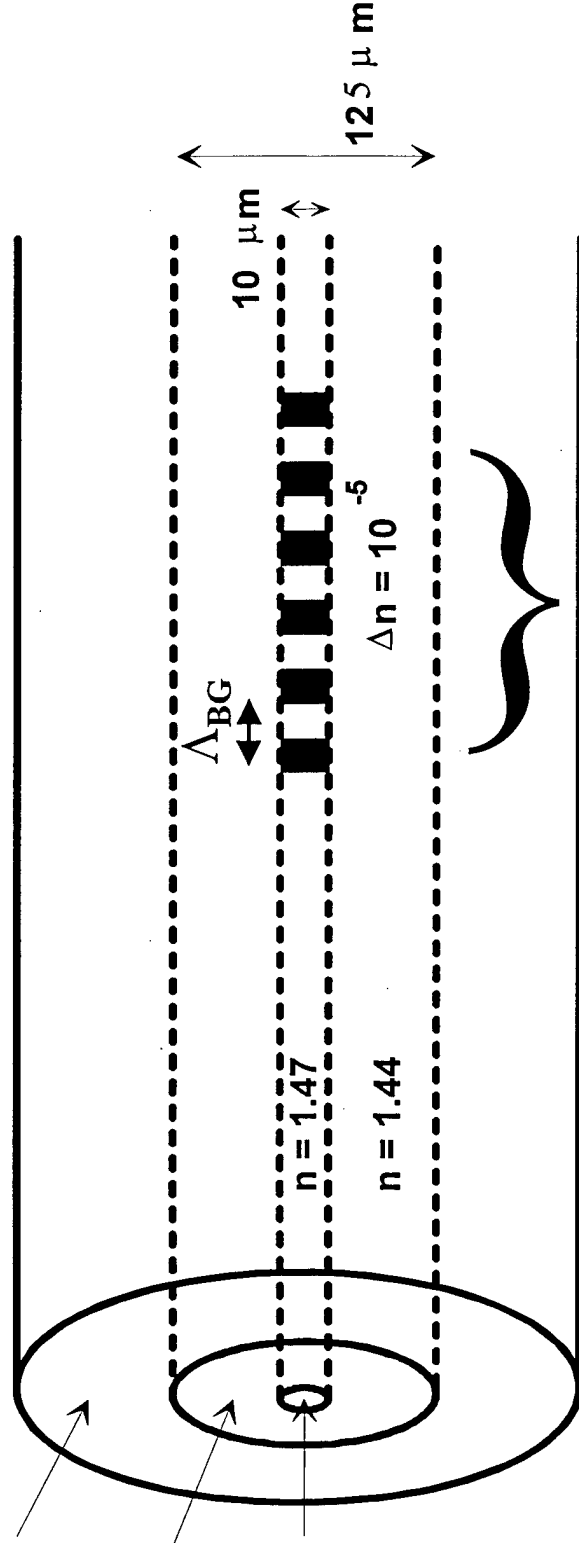


# OPTICAL FIBER BRAGG GRATING

Polyimide  
Buffer  
Coating

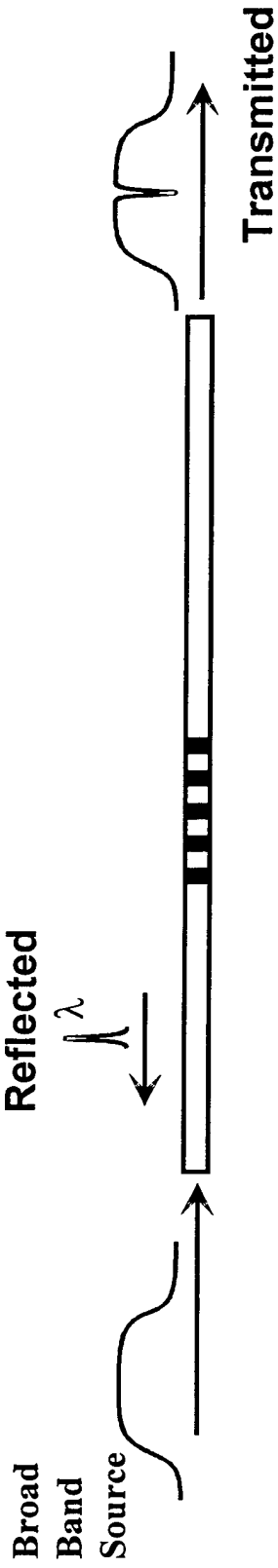
Glass  
Cladding

Glass  
Core

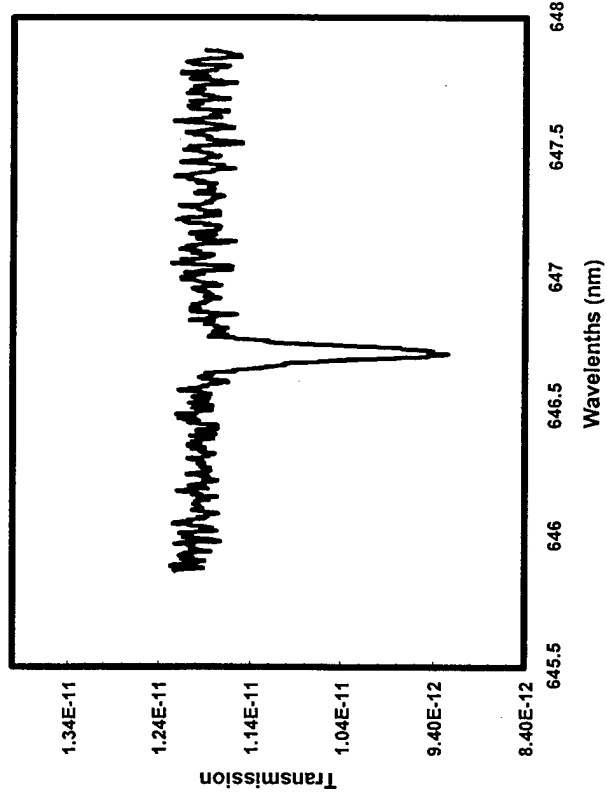


BRAGG GRATING

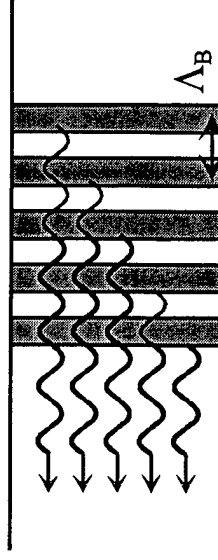
# BG SPECTRA



TRANSMISSION SPECTRA



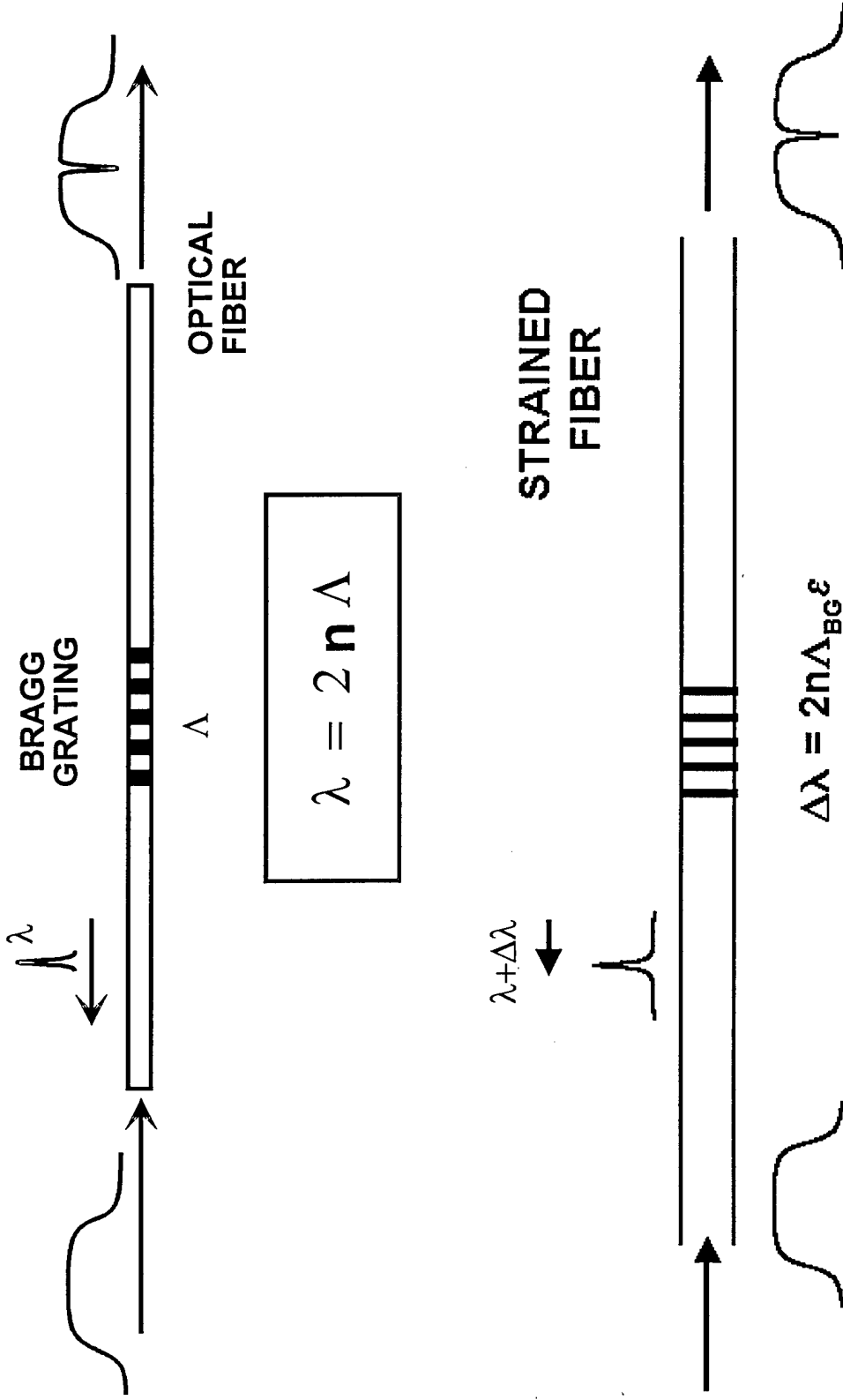
BRAGG GRATING



CONSTRUCTIVE INTERFERENCE

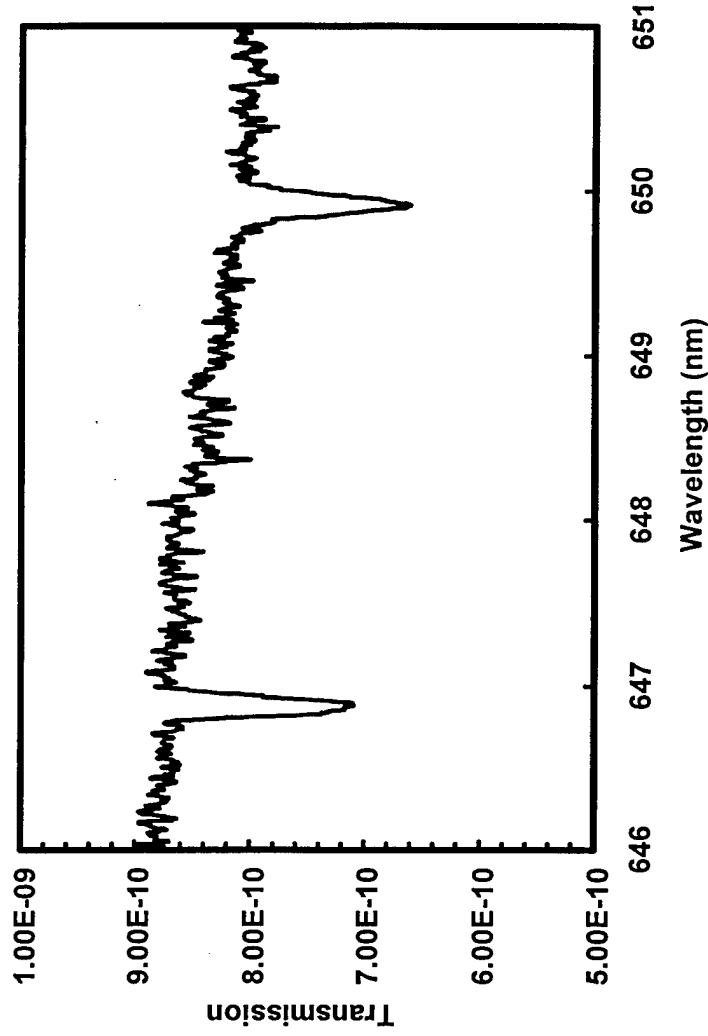
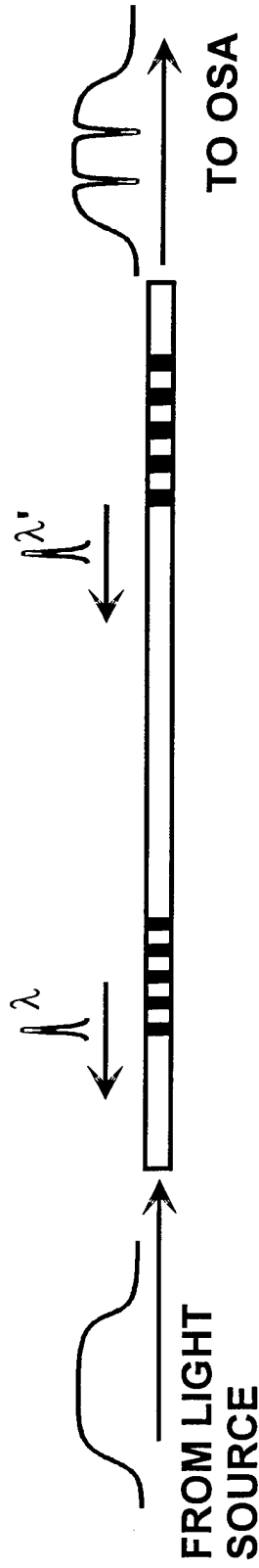
$$\lambda = 2 n \Lambda_B$$

# BRAGG CONDITION



Absolute strain sensing capability

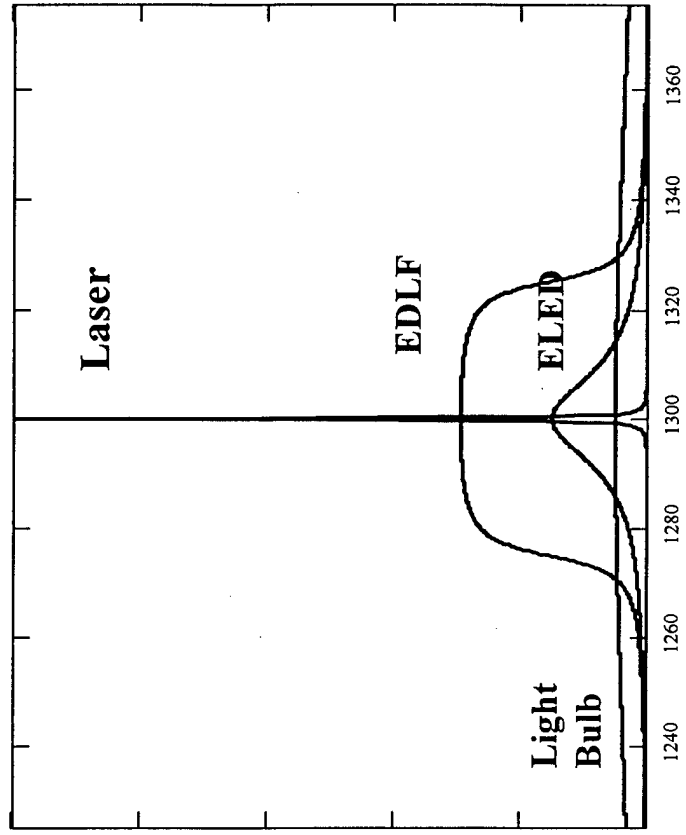
# ABSORPTION SPECTRA FROM TWO BRAGG GRATINGS



Multiplexing capability (large number of sensors in a single fiber)

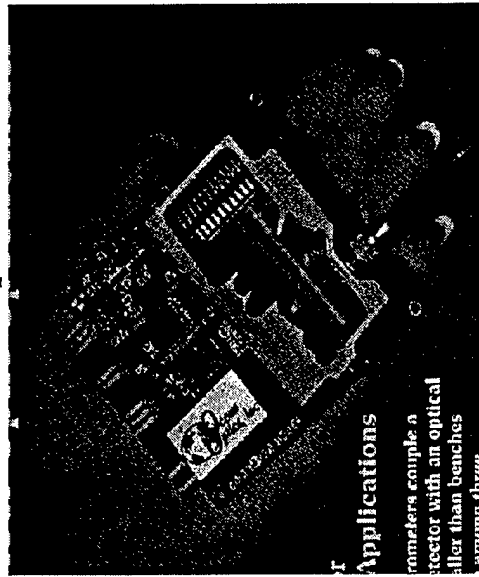
# LIGHT SOURCES

- Incandescent light source
- Light emitting diode(LED)
- ELED
- Super luminescent diode
- Erbium Doped Fiber laser
- HeNe Laser



# DEMODULATORS

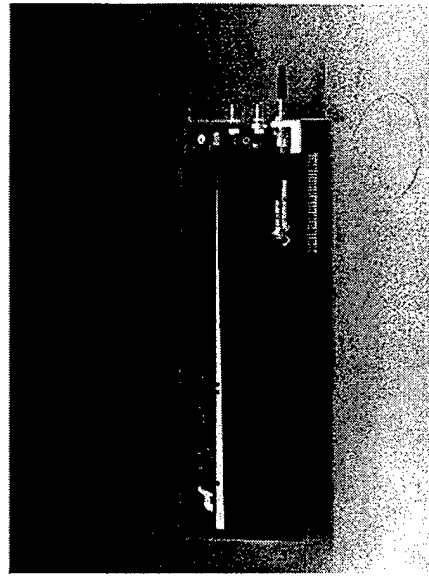
Ocean Optics Inc.



## Diffraction grid

Resolution = 0.5 nm  
Range 200nm - 11000nm  
Refresh Rate = 50 Hz

Research International Inc.

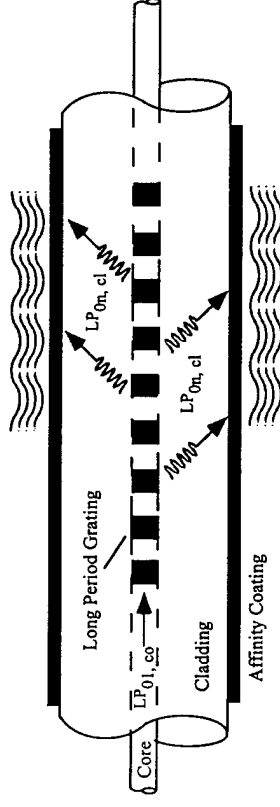


## Fabry-Perot Cavity

# CORROSION MONITORING

## FIBER OPTIC LONG PERIOD GRATING

- **OBJECTIVE:** TO DEVELOP A DISTRIBUTED FIBER OPTIC SYSTEM TO MONITOR THE DEVELOPMENT OF CORROSION
- **ADVANTAGES:**
  - IN A SINGLE FIBER MANY SENSORS CAN BE PLACED
  - EACH SENSOR CAN BE INTERROGATED INDEPENDENTLY
  - SENSOR CAN BE TAILORED TO SPECIFIC COMPOUNDS
  - NO OR MINIMAL ELECTRONICS ARE REQUIRED FOR MONITORING
  - SENSOR IS SMALL AND LIGHT
  - SENSOR IS INSENSITIVE TO EMI
  - SENSOR IS WAVELENGTH (NOT INTENSITY) BASED
  - CAN BE EMBEDDED OR SURFACE MOUNTED
- **TRANSITION POTENTIAL:** P-3C, JSF

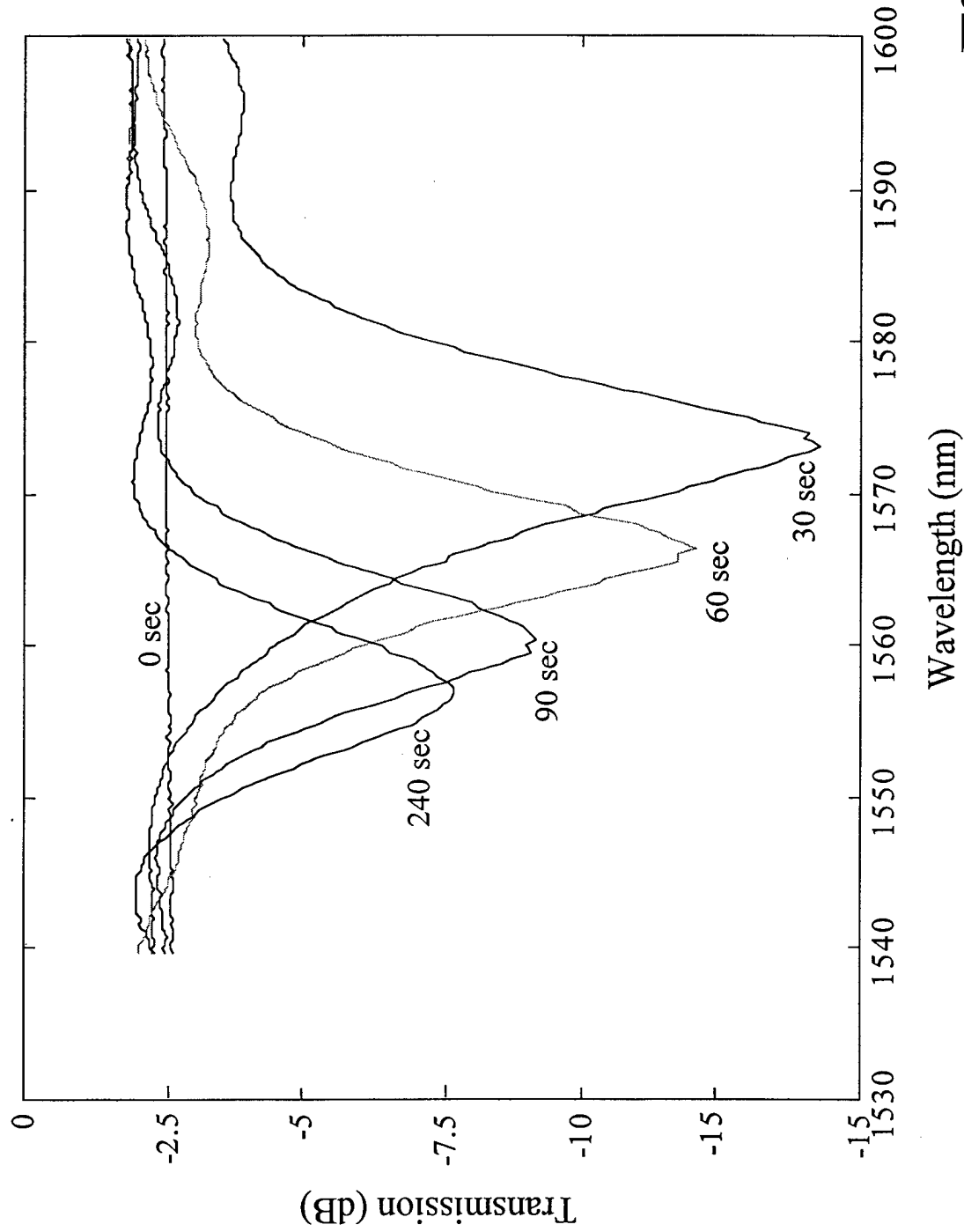


$$\lambda = (n_{co} - n_{cl}) \Lambda_{LPG}$$

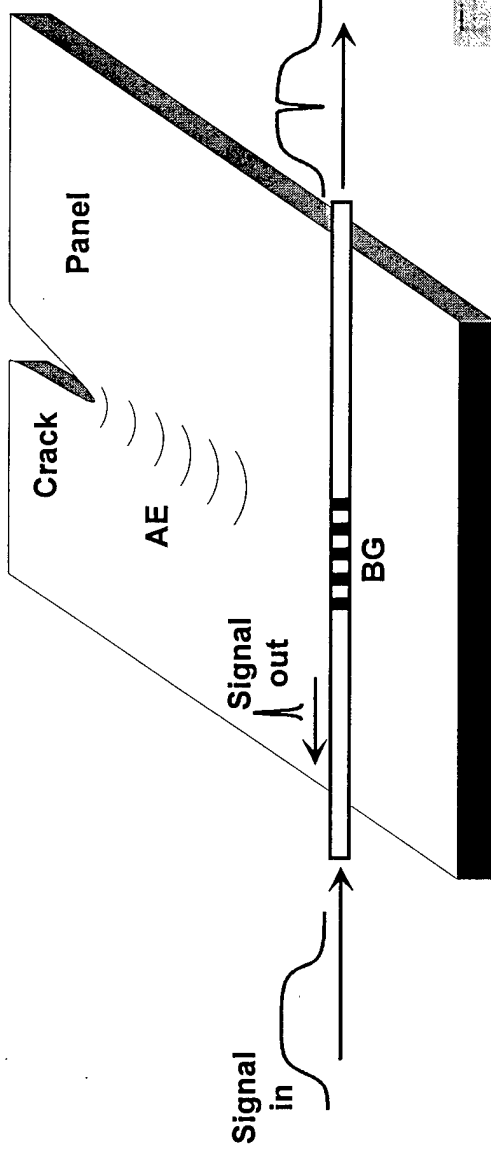




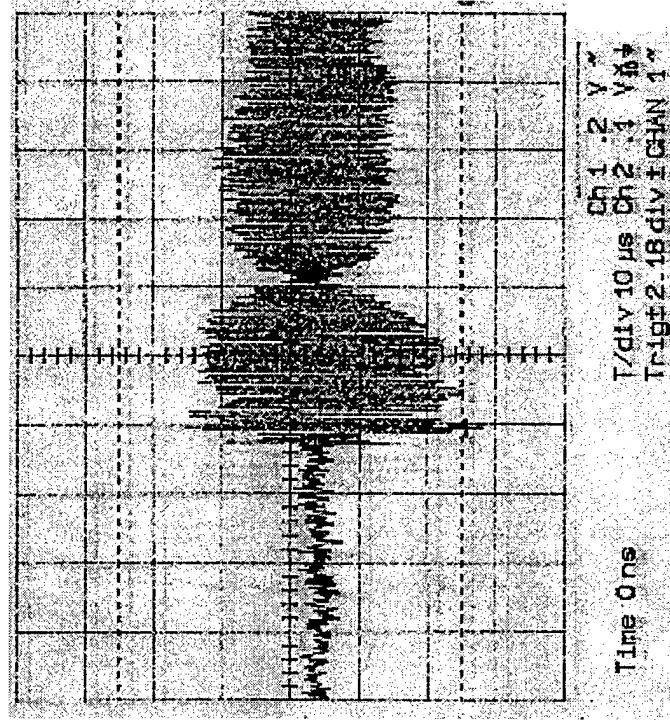
# LPG SENSOR SPECTRUM DURING WATER IMMERSION



# AE Event



## AE Event

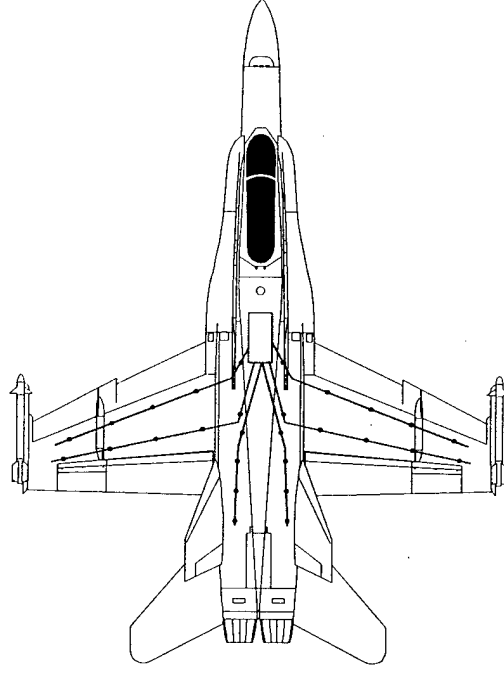
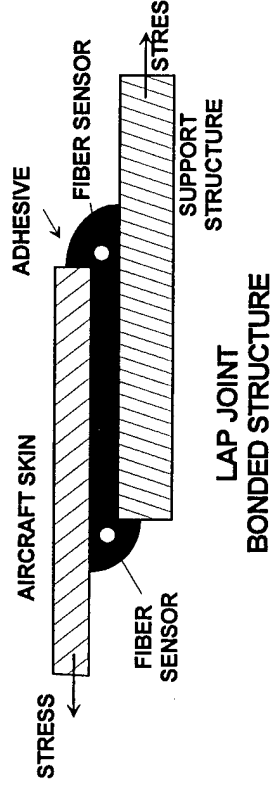


- Acoustic Emission event detected with a single fiber-optic Bragg grating

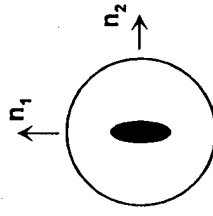
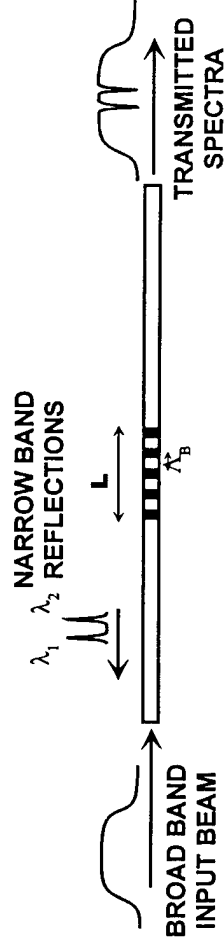
# BONDLINE MONITORING SYSTEM

## MULTI-AXIS FIBER OPTIC STRAIN MONITORING SYSTEM

- OBJECTIVE: TO DEVELOP A DISTRIBUTED FIBER OPTIC SYSTEM TO MONITOR BOND-LINE INTEGRITY
- ADVANTAGES:
  - IN A SINGLE FIBER MANY SENSORS CAN BE PLACED.
  - CAN SENSE AXIAL AND TRANSVERSE STRAINS.
  - EACH SENSOR CAN BE INTERROGATED INDEPENDENTLY
  - SENSOR IS SMALL AND LIGHT
  - SENSOR IS IMMUNE TO EMI
  - SENSOR IS WAVELENGTH (NOT INTENSITY) BASED
  - CAN BE EMBEDDED OR SURFACE MOUNTED
- TRANSITION POTENTIAL: P-3C, JSF, CBM, Aging Aircraft



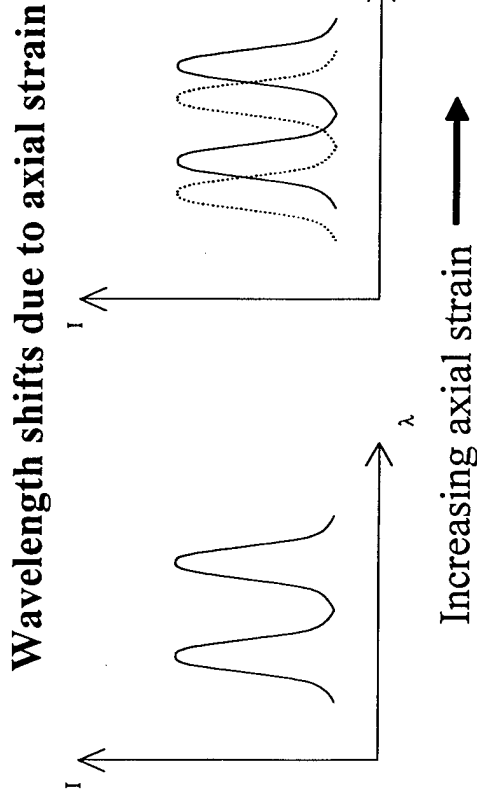
# Spectral Changes with Loading



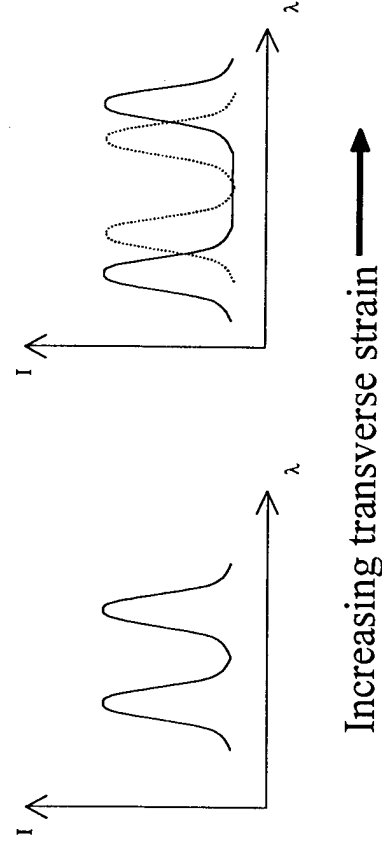
$$\lambda_1 = 2\Lambda_B n_1$$

$$\lambda_2 = 2\Lambda_B n_2$$

- Sensitivity is orientation dependant

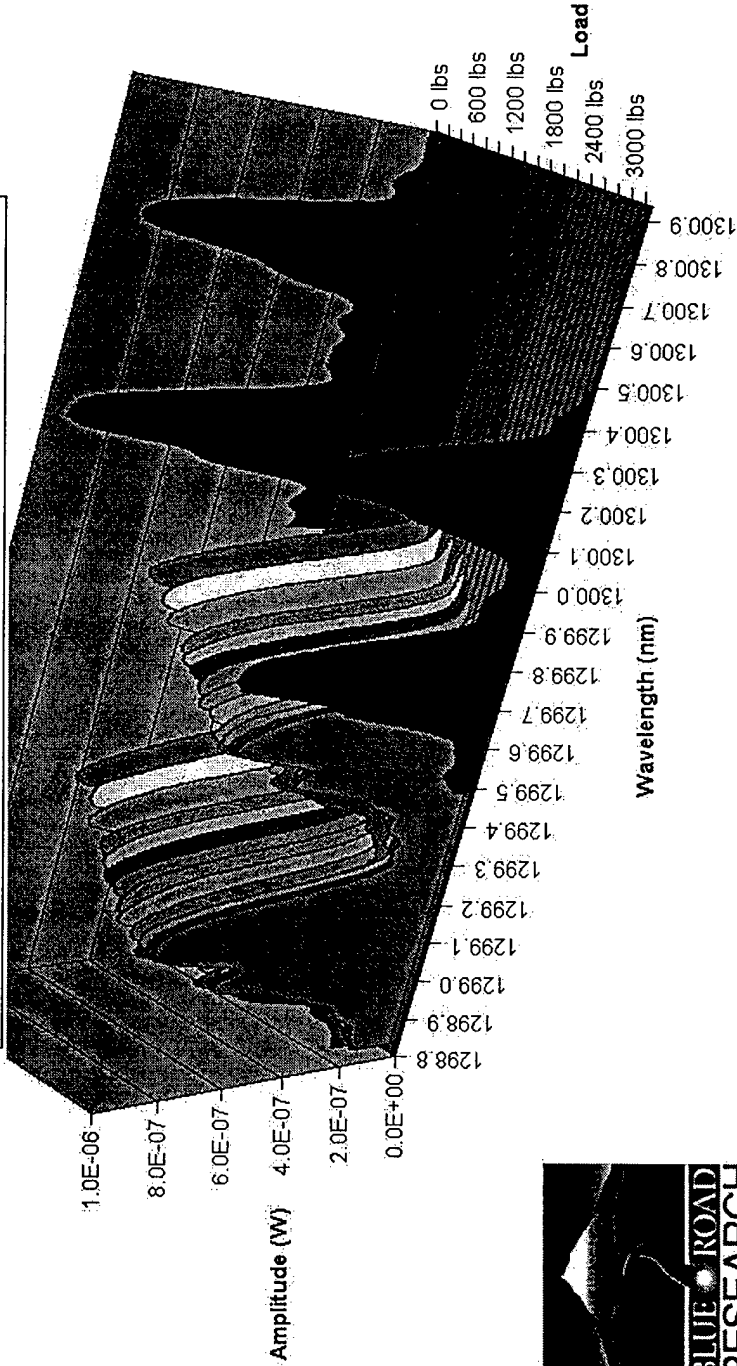


**Peak to peak separation due to transverse strain**



# Peak Separation vs. Load

1300 nm Spectrum Changing with Load for Adhesive Joint Retro-Fitted with Blue Road Research Multi-Axis Fiber Grating Strain Sensor Oriented at 90 Degrees

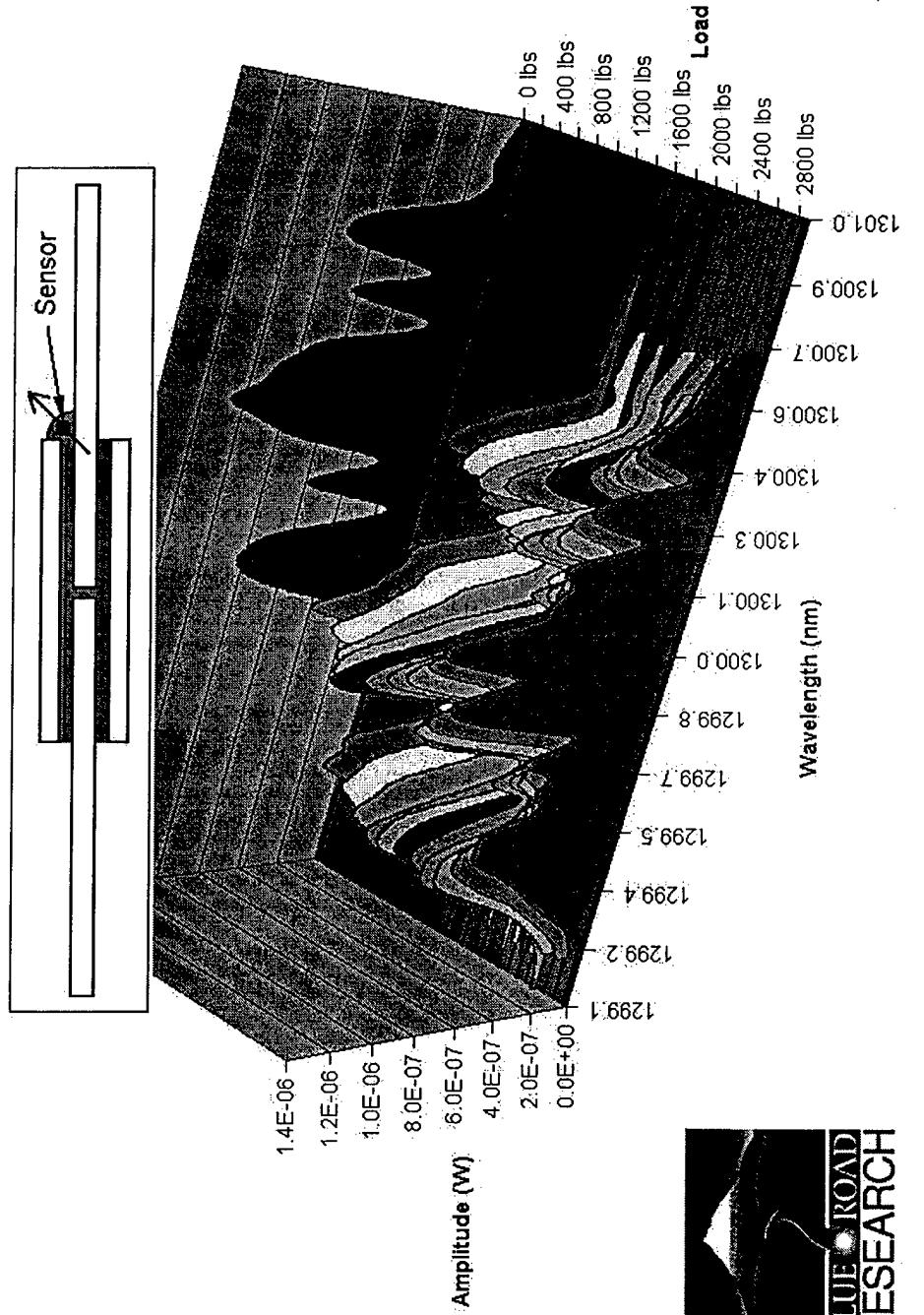


0 lbs	100 lbs	200 lbs	300 lbs	400 lbs	500 lbs	600 lbs	700 lbs	800 lbs	900 lbs	1000 lbs	1100 lbs	1200 lbs	1300 lbs	1400 lbs	1500 lbs	1600 lbs	1700 lbs	1800 lbs	1900 lbs	2000 lbs	2100 lbs	2200 lbs	2300 lbs	2400 lbs	2500 lbs	2600 lbs	2700 lbs	2800 lbs	2900 lbs	3000 lbs	3100 lbs	0 lbs
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# Peak Separation vs Load

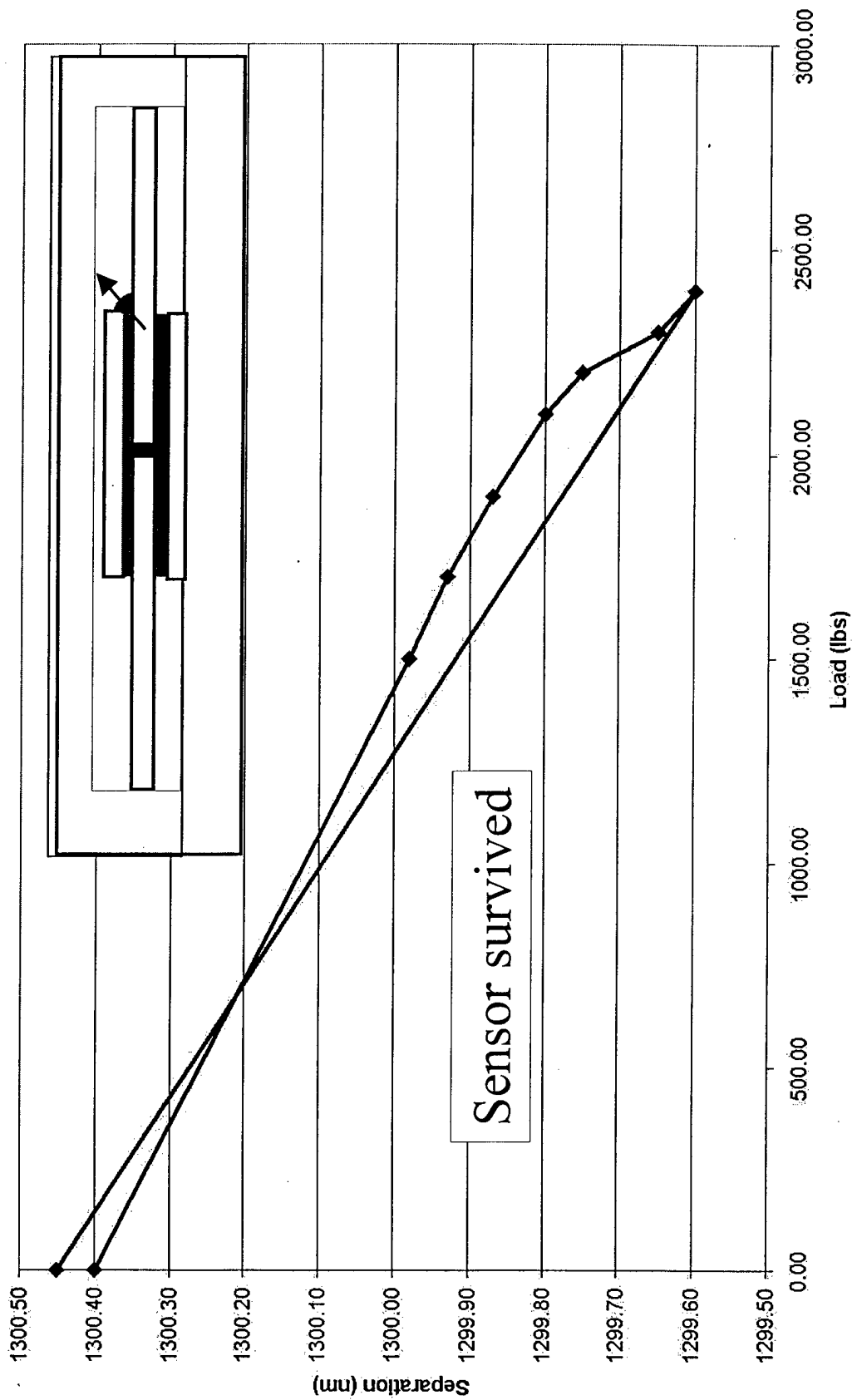
## high sensitivity orientation

1300 nm Spectrum Changing with Load for Adhesive Joint Retro-Fitted with Blue Road Research Multi-Axis Fiber Grating Strain Sensor Oriented at 45 Degrees



# Peak Separation vs Load

## high sensitivity orientation



# Fiber Sensors are Enabling

---

- Smart skins
- Smart patches
- Smart Materials
- Functional Materials (ex. Conformal antennas)
- Chemical and Biological detection in paints
- Designs for Inspection and LO materials: New and advanced structures and materials make NDI inspections very difficult
- Flight change due to combat or system damage
- Testing and Validation of structures and components
- Real-time in-flight testing and validation
- Waste Monitoring